Theses of PhD dissertation

Mapping and conservation of the reed wetlands on Lake Balaton

András Zlinszky

Eötvös Loránd University

Biology PhD School

Ecology, Conservation Biology and Systematics Program

Leader of the PhD school: Anna Erdei (PhD, D.Sc., corresponding member of the Hungarian Academy of Sciences)

Leader of the program: János Podani (PhD, D.Sc.)

Supervisor: Sándor Herodek (D.Sc.)

2013

Introduction

Emergent littoral vegetation holds a wide variety of microhabitats and is thus essential for sustaining ecological and species diversity in lake and river systems. It is also important for biogeochemical processes due to its high productivity, ability to immobilize macroscopic litter and filter non-point source pollution. The ecosystem services of shore wetland vegetation such as groundwater recharge and flood and erosion protection are also valuable for humans. On a landscape scale, wetlands offer habitat patches that are relatively undisturbed by direct human access, and can thus act as corridors for animal migration and refuge from the pressure of human presence. Despite their well recognized importance, lake shores with emergent vegetation are threatened by a number of human activities, including shore build-up, pollution, drainage and the introduction of alien species. International treaties and legislation have focused on the protection of wetlands: the Ramsar convention now governs the largest network of protected areas in the world, requesting "wise use and sustainable development"; the EU water framework directive summarizes the goal of reaching "good ecological status" for surface and ground waters; and the EU Flora-Fauna-Habitat Directive has established the Natura 2000 protected area network, where habitat quality is the main objective of management. These valuable initiatives share an important knowledge gap in case of large water bodies: information on the "natural" or at least "sustainable" state of these sites is often lacking.

This gap can be covered by a time series approach: by investigating historic conditions of large lakes and their change, reference information can be collected for judging the current state of the ecosystem. This requires accurate and spatially explicit historic datasets, together with a methodology for quantitative evaluation. Geographic Information Systems (GIS) are well suited to this task: they allow the spatially accurate handling of data, including overlaying, visualizing, querying and calculation. While firsthand field knowledge is the best source of information for ecological studies, the difficult access to littoral habitats and their position in biological sciences between terrestrial botany and limnology means that such information is very limited, and the time frame of the changes investigated can span several centuries. However, the toolkit of remote sensing has proved highly suitable for large scale ecological studies, and in particular, ecological mapping of wetlands. Especially the evolution of high-resolution airborne surveying methods and automatic processing has been increasingly useful for assessing wetland habitat quality and health. Considering the time before remote sensing surveys (before the 1940-s around Lake Balaton), only maps created from ground surveys are available, but the accuracy of these maps is often also sufficient for GIS-based quantitative evaluation. The oldest such maps were compiled before the industrialization of Hungary, and thus document the state of the landscape where human presence was sustained only on the basis of the local resources with no long-distance transport. Archive aerial photographs can be re-processed using GIS toolkits for quantification of wetland change. Finally, dedicated Airborne Laser Scanning surveys also support the creation of high resolution maps of vegetation species and health.

Objectives

Lake Balaton is a protected natural area, and there is considerable interest at national and international levels in sustaining the emergent macrophyte stands inside and near the lake. In order to implement adequate conservation measures, the natural state of the wetlands has to be assessed as a benchmark, the main causes for change have to be identified, and a methodology for monitoring the results of these initiatives has to be developed.

A: On the scale of the Lake Balaton watershed, the objectives were (1) to quantify the extent and changes of wetland vegetation, (2) to calculate the original unregulated water level changes of the lake, and (3) to assess the effect of water level control measures on the reed wetlands on the watershed.

B: On the scale of Lake Balaton itself, similar objectives were defined: (1) to quantify historic extents of littoral emergent vegetation and changes in its area, (2) compare these with biotic and abiotic environmental factors and determine a possible target for conservation measures that can facilitate regeneration of the reed belt. (3) In a broader frame, it was an aim to compare the observed key factor of reed die-back on Lake Balaton with results of reed die-back and regeneration studies on other lakes in order to find the common cause of reed area loss on many major European lakes.

C: In order to map the habitat quality and health of wetland vegetation, the goal was to create a new methodology that is relatively cheap, involves automatic data processing and can be applied over large areas in different settings.

Study area:

Lake Balaton is a large (594 km^2) shallow (average depth 3.3 m) mesotrophic lake with a catchment of 5775 km^2, mostly situated in low mountains and hills. It is located in Western Hungary, has a temperate continental climate and a water regime regulated by a sluice system at its outflow since 1863. The lake has four main basins, with the westernmost basin receiving the main tributary that brings half of the total inflow, and the easternmost basin connected to the outflow to the Danube. The lake floor slopes gently from North to South, holding large wetlands in the shallow and sheltered bays of the North-western shore, and a sandbar along the Southern shore adjacent to the deepest areas of the lake. The shallow depth and elongated shape of the lake creates strong seiche activity, displacing the water surface up to 50 cm vertically during strong wind events. The seiche of the lake causes intensive erosion on the NE and SW end of the lake and deposition of large-grained sediment in a sandbar along the south shore. The tributaries entering the lake feed vast wetlands that are separated from the lake by this sandbar. The water level of the lake is only registered since 1863, but written records document decadal fluctuations of about 3 meters. After regulation was initiated, the water level fluctuations decreased gradually as the drainage capacity of the canal was increased and management priorities changed. During the late 19^{th} century, the water level range was near one meter, decreasing gradually to 70 cm before the 1950-s and 30 cm from the 1970-s onwards due to more and more strict regulation. Since high water levels were considered beneficial for shipping and tourism, new regulation schemes always raised the official minimum water levels while keeping the maximum as high as possible without risking a flood. A period of drought between 2000 and 2003 brought a radical change in the water regime: the water level dropped 60 cm below the regulation minimum. From 2004 onwards, the water level increased again, and was within the prescribed limits until 2010.

Methods

Data sources for spatially accurate investigation can be maps, aerial photographs or airborne active scanners. Georeferencing is the process that brings these datasets to a common reference frame of the map projection coordinate system. This process involves (i) finding a mathematical representation of the mapping process, (ii) fitting points on the data to corresponding points in the spatial reference frame, and (iii) simplifying the information content to extract the relevant information. Comparing the extent and health state of wetlands in a time series allows identification of die-back and regeneration processes in time and space. In the next step, comparing these processes to localized environmental variables supports the identification of key influencing or controlling factors, which can be the targets of conservation efforts.

A: The earliest geodetic surveys of Lake Balaton were produced for water engineering and military purposes: the Krieger map and the Military Surveys of the Habsburg Empire. Knowledge of the surveying methods can be used to recreate the representation of the mapping process, and to select the appropriate mathematical transformation method for control point based georeferencing. In case of the Krieger map, which was compiled on a single map sheet by triangulation and levelling but without applying a mathematically based projection (to our best knowledge), this information supported the selection of a linear georeferencing algorithm, with a dense network of control points. In case of the First Military Survey map, which has map sheets that fit together at the edges, a cubic polynomial transformation was used with a moderate number of control points per map sheet and a mathematical constraint forcing the edges of adjacent pages to fit in the GIS. Maps produced later are readily available in georeferenced form and were incorporated in the GIS by reprojecting. As control points, objects had to be selected that existed at the time of the mapping and can be identified to the present day. These were mostly churches and other historic buildings or ruins, though in some cases, road crossings, bridges and hilltops have also been used. Extraction of the information relevant to the scientific objectives had to be carried out through raster-vector conversion, as vector datasets are more suitable for numeric area estimation. For the historic maps used in the study, the relevant features were wetland, forest and open water outlines, elevation and bathymetric contour lines. These were extracted through hand digitizing.

B: In order to span the time frame of reed expansion, die-back and regeneration, six archive aerial photo series were selected, from 1951, 1963, 1975, 1987, 2000 and 2003. These were panchromatic, true colour or infrared images collected from altitudes between 1500 and 5000 m. For aerial photographs, the mathematical representation of the mapping process was modelling of the path of light from the terrain through the camera optics to the film surface. For this purpose, camera models of the used sensors were created and applied in photogrammetric software. Control points were identified in the aerial photographs and in the already georeferenced 1:10000 topographic maps: road crossings, building and fence corners, harbour piers were used. Again, hand digitizing proved to be the best method for data extraction. In order to achieve good coverage of the study area and retain accuracy sufficient to detect changes of wetland extent in the order of one meter, a network of 73 sample sites was set up. In each of these sample sites, the reed-water boundary was digitized from the georeferenced aerial images at an onscreen scale of 1:100, and the resulting polygon clipped to the outline of the Lake.

C: In August 2010, an Airborne Laser Scanning (ALS) campaign was carried out with the aim of mapping the wetlands of Lake Balaton and Kis-Balaton. During ALS evaluation, the mapping process was represented by the knowledge of the travel time of each outgoing laser pulse between the sensor and the terrain surface together with the corresponding scan angle, as well as the position and attitude of the sensor, as logged by a GNSS/IMU unit. In this case, the step of fitting the data to ground control points was not necessary as the GNSS already supplied position information in a global reference frame. The resulting dataset was a point cloud that covered the whole lake shore and the Kis-Balaton wetland area. Relevant information in this case was extracted by converting from the vector points to a set of rasters describing variables of the vegetation structure, and performing a ruleset-based decision tree classification on these layers. Ground-surveyed reference polygons covering the full range of classification categories and also a number of mixed vegetation types were used to calibrate the algorithm, which was subsequently validated by a set of geo-tagged ground photographs.

New scientific results:

A1: Reed wetland vegetation extents were mapped and measured on the georeferenced First, Second and Third Habsburg Military surveys (1780-s, 1830-s and 1870-s, respectively). The area of wetlands on the 5775 km^2 drainage area of the lake changed from 361 km^2 during the late 18th century to 217 km^2 during the early 19th century (before the water level of Lake Balaton was lowered) and then to 186 km^2 by 1870. Most of the surface lost was in the upstream part of the wetlands, where the water was retained by vegetation despite the considerable slope of the valleys until the wetlands were artificially drained. Although several previous studies deal with changes of wetlands near Lake Balaton at a local scale, results have not been summarized before this thesis with a consequent processing method for the whole watershed.

A2: The earliest accurate measurement of the historic water level of Lake Balaton was identified as 107.0 meter above the Adriatic benchmark, as a medium water level in the year of 1776. The difference between two independent measurements of the water level elevation derived from two different elevation contours was 53 cm, the standard deviation of the measured values were lower than the documented average annual water level fluctuation of the lake during the studied period. This is in concordance with previous studies which reconstructed the water level of Lake Balaton based on recreation of precise levellings, but contradicts other authors who assumed the water level of the lake to be the same as the water level of the surrounding wetlands, and have estimated higher elevations for this period. This thesis proves that the present-day water level is closer to the historic water regime than previously believed.

A3: The main cause of reed wetland area loss around Lake Balaton was identified to be the canalization and drainage of wetlands. It was clearly demonstrated that nearly half of the wetland area on the Lake Balaton watershed was lost before the first documented direct human influence on the water level of the Lake. This thesis is contrary to previous theories which held the lowering of the water level of Lake Balaton responsible for wetland loss, and implies that local hydrological measures would be sufficient to re-create or sustain large areas of these wetlands without the need to raise the water level of Lake Balaton.

B1: The tendencies of reed area change between 1951 and 2003 were measured for a network of 73 sample sites of 200 meters (along shore) each, adding up to 17% of the total reed belt. A time series of 1951, 1963, 1975, 1987, 2000, and 2003 was set up, with a measurement accuracy of ± 1 meter for reed front movement. During the studied period, reed stands on the southern shore of the lake between the Zala river mouth and Balatonfenyves showed continuous expansion, and a similar tendency was observed for reed stands on the North-eastern shore of the lake or at sites where large-grained sediment is being deposited by tributaries or currents. The reed belt of the northern shore bays and coves lost 16 % of its area between 1975 and 1987, and then regained 5% of its area between 2000 and 2003.

B2: Reed area loss is obviously caused by many direct human activities on Lake Balaton at a local scale. However, the spatial extent of reed area loss and regeneration indicates a general controlling factor that acts in the same sense across the whole lake. Damage from fungal diseases, parasitic insects or grazing by muskrats, swans or grass carp have observed on Lake Balaton, but since no large-scale fluctuation in their activity has been documented parallel with the reed area changes measured, they could not have been this key factor. Eutrophication of the lake was suspected to cause die-back, but the spatial trophic gradient along the axis of the lake has been proven not to have caused a similar gradient in the health of reed stands. Reeds standing in eutrophic waters in the Keszthely basin of the Lake in 2000 grew vigorously, while reed areas under mesotrophic conditions in the Eastern basin in the 1970-s died back. Between 1975 and 1987, the minimum water level of the lake was raised by 35 cm (10% of the average water depth). Between 2000 and 2003, the water level of the lake reached a 50-year minimum 60 cm below regulation levels. The changes of reed condition and area on the Northern shore of the lake reflect these changes in water level, while the low water depth of the Southern shore stands explains why they were not affected. Thus it is concluded that the lack of periodic low water levels is the key factor of reed die-back on Lake Balaton, and should be addressed by a change in water level management for the benefit of the reed habitats. This thesis disproves hypotheses of previous authors who suggested that eutrophication, salinification of the water, grazing pressure or wave action could be the most important causes of reed die-back of the lake.

B3.The literature of the symptoms identified as “European reed die-back” was reviewed and the suggested causes of reed loss or regeneration were compared at a European scale. Previous studies have identified the beneficial effect of water level drawdowns on reed if the sediment of the wetlands was completely uncovered by water. Flooding has been known before to cause reed area loss. However, the current study shows the negative effect of the lack of low water levels without actual flooding, and also the positive effect of low water levels without the sediment of the stands being uncovered. Water level regulations were therefore identified as the key factor of reed die-back and regeneration on Lake Balaton. In particular, the lack of low-water periods has been proven to cause die-back over the whole North shore of the Lake, while below-average water levels allow stabilization of the reed front and extremely low water coverage initiates regeneration of the reed belt. Measurements of redox potential carried out by BLRI staff between 2000 and 2004 have shown lower redox potentials in the sediment of reed stands affected by die-back than in the sediment of healthy stands, with low water levels inducing higher redox potentials that diminished this difference. According to the literature, water level acts by controlling the availability of oxygen for the decomposition of organic matter in the submerged sediment. The oxygen demand of the sediment limits the distance oxygen can travel along the aerenchyma of the rhizome, and thus the availability of oxygen to the apical rhizome meristems. Oxygen shortage of the rhizome tips inhibits apical dominance, activating dormant buds on the vertical rhizomes and resulting in clumped growth. While this mechanism has been suggested by laboratory experiments, it has not been proven before through measurements in a natural setting involving both high and low water levels. The results are expected to be applicable to other European lakes, where reed die-back has also been observed and water levels are often regulated, and thus could be a general basis for dealing with European Reed die-back.

C: A novel method for reed wetland vegetation genus and health mapping with Airborne Laser Scanning (ALS) has been developed. An ALS survey of Lake Balaton has been planned and carried out, and an algorithm developed that automatically classified the ALS dataset to a map of wetland and non-wetland areas; Phragmites, Carex, Typha and Scirpus dominated wetlands; and healthy, stressed, ruderal and die-back Phragmites areas. Accuracy was tested against an independent dataset and was found to be 82.7% with a Cohen´s Kappa of 0.80 for the 9 classes involved. This is comparable to or better than hyperspectral imaging, ALS fused with multispectral data or field mapping studies. The use of single-channel airborne laser scanning is completely new for ecological mapping in wetland environments, but the classification accuracy is satisfactory and the method proposed is expected to be robust enough for application in other study sites. The connection between the measured parameters and the actual structure of the studied vegetation classes in the field is well understood. The relatively easy access to ALS data facilitated by nationwide surveys means this method has a high potential for cheap, quick and accurate mapping of wetland presence, structure and health.

Conclusions:

In historic times, the vast wetlands surrounding the lake formed an interconnected series of habitats suitable especially as breeding areas and migration corridors for wildlife. The decrease in the area of these reed wetlands does not reflect the drainage induced by the regulation of the Lake itself, which means that the irreversible water level changes of Lake Balaton do not have an irreversible effect on the adjoining wetlands. This is best demonstrated by the restoration of the Kis-Balaton wetland system.

While many of the reed areas around the lake exist to the present day, the connection to the lake has been restricted by urban and transport infrastructure development around the shore. The littoral reed stands of Lake Balaton have to provide many of the functions that were previously sustained by the tributary wetlands. These littoral macrophyte beds were affected by European reed die-back, a process that has caused major loss of reed area. The quantitative study of the changes of the reed stands in space and time identified the reason for this die-back: the lack natural water level fluctuation and especially periods of low water. In the future, conservation efforts aiming to reduce reed die-back on Lake Balaton or elsewhere have to address the water level. Since high water levels are in the interest of tourism, management has to balance ecological needs and human preferences. The ALS-based reed health mapping algorithm allows efficient quantification of the health of wetland vegetation over large areas. It is therefore a suitable early warning system that can indicate whenever water drawdowns are necessary.

The theses include methodological development for mapping wetlands in historic, recent and real time, and exploit these methods to solve a pressing question of littoral vegetation conservation in Europe.

PUBLICATIONS IN THE TOPIC OF THE DISSERTATION:

András Zlinszky, Viktor Tóth, Piroska Pomogyi, and Gábor Timár (2011): Initial Report of the AIMWETLAB project: Simultaneous airborne hyperspectral, LIDAR and photogrammetric survey of the full shoreline of Lake Balaton, Hungary.

Geographia Technica, No. 1, 2011, pp. 101-117.

András Zlinszky (2011): The GIS-based reconstruction of historic water levels of Lake Balaton and the surrounding wetlands.

Ecology of Lake Balaton / A Balaton Ökológiája 1 (1)

András Zlinszky (2010): Measuring historic water levels of Lake Balaton and the neighbouring valleys. *Acta Geod. Geoph. Hung., Vol. 45(1), pp. 39–47 (2010)*

DOI: 10.1556/AGeod.45.2010.1.7 ***IF:0.28***

András Zlinszky (2009): Georeferencing the first bathymetric maps of Lake Balaton, Hungary

Acta Geod. Geoph. Hung., Vol. 44(1), pp. 79–94 (2009)

DOI: 10.1556/AGeod.44.2009.1.8 ***IF:0.28,*** independent citations: 2

András Zlinszky, Gábor Molnár, and Sándor Herodek (2008): Digital analysis of the geomorphology of the Lake Balaton (in Hungarian with English Abstract), Hidrológiai Közlöny (Hungarian Bulletin of Hydrology) 89/6, 239-241

PAPERS SUBMITTED FOR PUBLICATION

András Zlinszky, Werner Mücke, Hubert Lehner, Christian Briese, and Norbert Pfeifer: Is Airborne Laser Scanning suitable for monitoring wetland ecosystem health?

Remote Sensing (in review).

Sándor Herodek, András Zlinszky, Viktor Tóth: XXXX

Aquatic botany (submitted)

CONFERENCE PRESENTATIONS IN THE TOPIC OF THE DISSERTATION:

A. Zlinszky, W. Mücke, H. Lehner, C. Briese, and N. Pfeifer (2011): Airborne Laser Scanning based mapping of wetland health on Lake Balaton

Full-Waveform Airborne Laser Scanning for Vegetation Analysis, University Workshop of the Institute of Photogrammetry and Remote Sensing of the Vienna University of Technology, 29-30. September 2011

A. Zlinszky, W. Mücke, C. Briese, and N. Pfeifer (2011): Genus and stress mapping of reed wetlands with Airborne Laser Scanning

LIII. Hydrobiology Days Conference Tihany, Hungary, 5-7- October 2011. (in Hungarian)

A. Zlinszky (2010): First, Second and Third Habsburg Military Surveys: documents of the transition of Lake Balaton from natural to artificial hydrologic regime. Poster

EGU General Assembly 2010, Vienna, Austria, 2-7 May.

Geophysical Research Abstracts,Vol. 12, EGU2010-869, 2010

A. Zlinszky (2010): GIS-based reconstruction of historic water levels of Lake Balaton and the neighbouring valleys .

LII. Hydrobiology Days conference, Tihany, Hungary, 6-8 October 2010 (in Hungarian)

A. Zlinszky, Viktor Tóth, and Sándor Herodek (2010): Long-term aerial survey of the reed stands of Lake Balaton, Hungary

International Symposium on Advanced Methods of Monitoring Reed Habitats in Europe, Illmitz, Austria, 25-26 November 2010.

A. Zlinszky (2009): Measuring historic water levels of Lake Balaton and tributary wetlands using georeferenced maps.

EGU General Assembly 2009, Vienna, Austria, 19-24 April,

Geophysical Research Abstracts, Vol. 11, EGU2009-654, 2009

A. Zlinszky and G. Molnár (2008): The first bathymetric maps of Lake Balaton, Hungary.

Poster

European Geosciences Union General Assembly 2008, Vienna, Austria, 13-18. April

Geophysical Research Abstracts, Vol. 10, EGU2008-A-04254, 2008

A. Zlinszky, V. Tóth, and S. Herodek (2008): Long-term changes in the reed stands of Lake Balaton (in Hungarian). Plenary presentation

XXVII. Annual Assembly of the Hungarian Biological Society, Budapest, 25-27 September 2008

A. Zlinszky, G. Molnár, and S. Herodek (2007): Digital analysis of the geomorphology of the Lake Balaton.

XLIX. Hydrobiology Days conference, Tihany, Hungary, 3-7 October 2007 (in Hungarian)

A. Zlinszky, S. Herodek, and V. Tóth (2006): The aerial photograph-based examination of water level dependent changes in reed stands on Lake Balaton.

Conference for Environmental History, Dept. of Paleontology of the Eötvös Loránd University, Budapest, 8-9 February 2006. (in Hungarian)

A. Zlinszky, S. Herodek, and V. Tóth (2006): Monitoring long-term changes in the reed stands of Lake Balaton by interpretation of archive aerial photographs.

XLVIII. Hydrobiology Days conference, Tihany, Hungary. 4-6. October, 2006. (in Hungarian)